THE RELATION OF FORESTS TO STREAM CONTROL

By Hon. Gifford Pinchot,
United States Forester, Washington, D. C.

The phenomenal development of industry and the consequent increased demand for transportation have turned attention to our most natural means of inland transportation—the lakes and rivers. It has forced us to realize that our streams, in spite of the tens of millions of dollars appropriated for their development, are becoming less navigable. Increasing amounts of sediment are deposited each year in their middle and lower courses, while the flow of the streams themselves becomes less regular. Navigable with difficulty, if at all, during the summer, they become turbulent and turbid during the spring, overflow their banks, and often carry destruction to life and property. The skill of our engineers is taxed to the utmost to keep harbors and rivers free from the constantly recurring deposits of sediment. Because of the rapidly increasing tonnage and draft of vessels, it is not sufficient merely to maintain the present depth of our rivers and harbors. Their depth must be constantly increased or they will gradually fail to accommodate the larger vessels, and such of them as fail must finally be abandoned altogether.

More powerful dredging machinery is constantly coming into use. Efforts are common to prevent the deposit of sediment by confining streams to channels narrow enough to accelerate the current and so lessen the rate of deposition. This method of channel adjustment has accomplished great good in improving the courses of many of our rivers, but it cannot and does not claim to regulate in the least the water supply of the streams.

The method of storage reservoirs, extensively tried in France, has been suggested as a method of river improvement in the United States. Reservoirs filled in the spring freshet season serve to increase the flow later in the year when the streams run low. Floods may thus be prevented, and the immense loads of silt which they would otherwise have brought down are thus kept from being dropped by the slow current in the lower channel. Theoretically

this method of storage reservoirs will accomplish all that can be desired in regulating stream flow and preventing excessive deposition, if only adequate storage capacity is available. In practice, too, it will doubtless be efficient in places where the erosion is not rapid. But the great disadvantage of this method, as is proved by the experience of the French engineers, lies in the fact that the reservoirs themselves become clogged with detritus and must sooner or later, varying with the forest conditions and the character of the topography drained, be either abandoned or maintained by constant clearing out at large expense.

The engineers of the United States Reclamation Service fully realize that the amount of solid matter carried by a stream is a very serious problem in connection with the construction of storage reservoirs for irrigation purposes. Streams from barren watersheds abound in violent freshets which carry with them eroded sediment, to be deposited in the first pool of still water they encounter, and thus reduce the storage capacity of the reservoirs into which they flow. Mill dams completely filled with sediment are to be seen everywhere, and offer good demonstrations of the damage to storage reservoirs from silting.

The regulation of streams by storage reservoirs is really an imitation of what nature is able to accomplish by the forests. Forests at the sources of the streams are veritable storage reservoirs, and without them no artificial remedy can be either adequate or permanent. Erosion destroys reservoirs, and must be controlled if reservoirs are to succeed. This can be done only by conserving or restoring the forests. The forest cover alone can reduce the amount of sediment carried by water, and make possible the permanent improvement of inland waterways. To check erosion by reforestation, work must begin in the highlands, because there the slopes are steepest, the rainfall greatest, and the action or frost most considerable, and therefore the process of erosion is most rapid and the results most destructive.

No one will deny the necessity for engineering methods to cope with the moderate deposits of silt and the seasonal irregularities in flow, which may indeed be lessened by forest cover, but which are unavoidable so long as the sun shines and the rain falls. Yet it remains true that a forest cover interposed between rain and rock affords the best natural means for regulating streams and reducing

the loads of detritus. Without such a forest cover every attempt to improve the regimen and the channel of a stream will be little more than a temporary expedient.

Both wide experience and scientific investigation have shown that there are two functions exercised by the forest in relation to stream-flow.

1. Its tendency to reduce the difference between high and low water, an influence which is of most importance in the distribution of flood crests, and in maintaining a steady flow of water during the different seasons of the year and during cycles of dry and wet years.

2. Its value as a surface protection against soil erosion, thus reducing the solid burden of storm waters, and decreasing the deposits of sand and silt, which are the causes of shallow and changing channels.

These two functions follow from the very nature of the forest as a soil cover. The roots of trees penetrate through the soil to the underlying rock, where they fix themselves in the crevices, and in this way hold in place the loose soil and prevent slipping and washing. The crowns of the trees break the force of the rain and also protect the soil from being carried away to the lower valleys during heavy storms. The leaves and the branches allow the rain to reach the ground but gradually; after a rain, water continues to drip from the crown for several hours, and the soil is thus enabled to absorb the greater part of it. Screened from the rays of the sun and covered with a surface mulch of fallen leaves and humus, the soil remains loose and granular in structure and is therefore capable of imbibing and retaining water with sponge-like capacity. It is strewn with fallen leaves, branches, and trunks, and traversed by a net-work of dead and live roots which impede the superficial run-off of water after heavy storm. This retardation of the superficial run-off allows more of it to sink into the ground through the many channels left in the soil by decayed roots. Surface run-off of rain water is wasteful and destructive, and unless artificially controlled serves as a rule no useful purpose and may inflict great loss. Sub-surface drainage makes the best use of the total precipitation that reaches the ground. It serves both for the sustenance of plant life and for the flow of streams. Accordingly the agency of the forest cover in increasing the seepage run-off at

the expense of the surface run-off is the most important function which the forest performs in relation to water supply.

A common conception of the effect of forest destruction upon climate is that it reduces the amount of rainfall. Because springs become dry and streams shrink in a deforested region, it is assumed that less rain must fall. Whether or not there be any truth in this assumption (I believe there is), it is certain that the main cause of the observed facts is the profound effect which forest destruction has upon the course which the water takes after it reaches the ground. The greatest influence of the forest is not upon the amount of rain which falls, but on what becomes of the rain after it falls. The water that sinks into the ground passes for greatly varying distances beneath the surface before reappearing, and is thus drawn off gradually from the forested watershed and supplies the brooks with pure water relatively free from detritus.

How active a part is played by the forest in regulating the run-off is clearly shown by actual measurements of the flow of streams which drain forested and unforested watersheds. A typical illustration of streams from barren, treeless watersheds may be found in the flow of Queen Creek, in Arizona.[1] This stream discharges only in violent freshets, recurring usually as great flood-waves which subside almost as soon as they arise. The area of the drainage basin is 143 square miles, of which 61 per cent is above an elevation of 3,000 feet. The rainfall is estimated to be about 15 inches. The maximum flood discharge of Queen Creek in 1896 was 9,000 cubic feet per second, and the mean discharge was 15 cubic feet per second; during a large portion of the year the stream was entirely dry.

Cedar Creek, in Washington, is typical of streams flowing from timbered watersheds.[2] The basin of Cedar Creek lies on the western slope of the Cascade Mountains and is covered with a dense forest and a very heavy undergrowth of ferns and moss. The drainage area is the same as that of Queen Creek, 143 square miles. The precipitation for the year 1897 was about 93 inches for the lower portion of the basin, and probably 150 inches on the mountain summits; in spite, however, of the fact that

[1]Eighteenth Annual Report of the Geological Survey, Part 4, Hydrography.
[2]Nineteenth Annual Report of Geological Survey, Part 4, Hydrography.

the precipitation in Cedar Creek basin was from six to nine times more than that in Queen Creek basin, the maximum flood discharge of Cedar Creek for 1897 was but 3,601 cubic feet per second, as against the 9,000 cubic feet of Queen Creek. On the other hand the flow of Cedar Creek was continuous throughout the year, and the minimum discharge was never less than 27 per cent of the mean for the year. The mean discharge of Cedar Creek was 1,089 cubic feet as against 15 feet for Queen Creek. This radical difference in the behavior of the two streams can be explained only by the difference in the soil cover of the two basins. Cedar Creek basin is covered with a heavy forest, while Queen Creek basin is almost entirely bare, with but a few scattering pinion trees and a little brush or grass.

Mr. Marsden Manson,[3] in discussing the stream flow from certain points on the Yuba River basin, California, makes a very interesting comparison between its two branches, North Fork and South Fork, of which the first has a forested and the second a denuded basin. Both of the catchment areas lie on the western slope of the Sierra Nevada, and have exposures of marked similarity.

The south branch of the North Fork has a watershed area of 139 square miles, which gave in 1900 a maximum run-off of 113 cubic feet per second, or 0.8 cubic feet per second per square mile. This drainage area is well covered with timber and brush, and for four months gives a minimum run-off of 1,441,125,000 cubic feet.

On the South Fork, above Lake Spaulding, there is a watershed of 120 square miles from which the scattering timber that once existed has been cut off. The run-off of this area is practically nothing for four months in each year, because of this absence of forests. If this area were afforested and gave a minimum run-off of 0.8 cubic foot per second per square mile, the discharge would be 100 cubic feet per second, or equivalent to 1,036,800,000 cubic feet of effective storage capacity. To supply water for mining and power purposes a number of costly storage reservoirs have been built on the South Fork. By reforesting the small watershed a natural reservoir would be created whose storage capacity would

[3]Features and Water Rights of Yuba River, California, Bulletin 100, Office of Experiment Stations, U. S. Department of Agriculture. 1901.

be almost equal to the storage capacity of all the reservoirs[4] above Lake Spaulding dam.

A careful study of the behavior of the streamflow on several small timbered and non-timbered catchment areas in the San Bernardino Mountains of Southern California, made by Professor Toumey for the Forest Service in 1902, brought out in a most convincing manner the effect of the forest in decreasing surface run-off and sustaining the flow of mountain streams. Three timbered drainage areas were studied. These gave during December—a month of unusually heavy precipitation—a run-off of but 5 per cent of the heavy rainfall for that month; during the following months of January, February and March, they gave a run-off of approximately 37 per cent of the total precipitation, and three months after the close of the rainy season still supported a well-sustained streamflow. At the same time, the similar and neighboring non-timbered catchment area under observation gave during December a run-off of 40 per cent of the rainfall, and during the three following months a run-off of 95 per cent. In April the run-off was less than one-third of that from each of the forested catchment areas, and in June the stream from the non-forested area was dry.

Streams flowing from barren, treeless watersheds, carry an amount of gravel, sand and soil which is simply enormous compared to the amount in streams from timbered areas. Thus the United States Geological Survey determined the amount of silt carried by the Gila River at the Buttes, a stream whose basin and regimen is similar to that of Queen Creek, of Arizona, to be 10 per cent of the volume wet or 2 per cent of solids. To appreciate these figures it must be remembered that one-fourth of one per cent of solid burden in the stream is enough to make the water turbid.

As long as the ground is protected by a natural covering of forest growth, rainfall has very little erosive action. It is only after the ground is laid bare by the removal of the forest that the erosion of the soil attains dangerous proportions.

There has, of course, always been, even when the natural forests were unimpaired, some erosion, especially in the watersheds of streams in the Southeast and Southwest, but not to the extent which now obtains, and the present erosion is not only

[4]The aggregate capacity of all the reservoirs is 1,375,000,000 cubic feet.

excessive, but is yearly increasing. It is the price, and in a large measure the product, of necessary agricultural and industrial development under defective methods of work. According to studies of Humphreys and Abbott the wearing down of the earth's surface over a region such as the Mississippi Valley is something like one foot in five thousand years, independent of human action. At such a rate of erosion the amount of sediment carried by the Mississippi River before the dawn of civilization could not be more than 70,000,000 tons per year. According to Professor Shaler the wearing down of the Mississippi Valley under complete tillage will be about the same as that of the Valley of the Po in northern Italy, or one foot in one thousand years. At such a rate of erosion, the solid burden of the Mississippi River should be 350,000,000 tons. But the amount of solid matter carried every year by the Mississippi River was estimated several years ago to be 400,000,000 tons. In other words, the erosion had then reached, if not exceeded that of the Po Valley. It is greater now. The formation of soil through underground decay of the rocks cannot keep pace with such a rate of erosion. Unless measures are taken to check it the fertile layer of soil must gradually disappear, as has happened already over large areas in the Old World from precisely similar causes.

The ruinous effects of the destruction of mountain forests upon the navigability of streams and the cultural results of human labor have long been felt by most European countries and attempts have been made to remedy them. France in particular has learned by bitter experience how terribly the lowlands suffer when the mountains lose their forest cover, and has now proved by practical demonstrations that the losses produced by forest destruction can be repaired only by reforestation.

During the French Revolution of 1789 extensive clearings were made in the forests of the Provençal Alps. The French Government early recognized the danger which such bare areas threatened to property and industry, and emphasized the importance of reforestation. In 1842 the classical investigations by Surell made it evident that forest clearing was responsible for most of the damage caused by mountain torrents, and that in reforestation lay the remedy. Laws were enacted in 1860 and 1864 which recognized that reforestation, to improve streamflow, to restore the soil, and to regulate torrents was of public utility, and therefore that

it was a duty of the government. Two methods were adopted to carry out the work. Government assistance for reforestation voluntarily undertaken by communities or private individuals; and compulsory reforestation by means of temporary dispossession, whereby the option was left with the owner of recovering his lands either by reimbursement of cost or by surrendering one-half the area to the government. The work was entrusted to the French Forest Service, and from 1861 to 1877, inclusive, an area of 233,590 acres of mountain land was put into forest or grass at a cost, including certain incidental expenses, of $2,900,000. At the close of the last century the fund appropriated by the French Government for protective afforestation amounted to $12,500,000 in round numbers, of which $4,900,000 went toward purchase of land and $7,600,000 was spent in improvement of streams and reforestation of their drainage basins. The work resulted in bringing under control a number of torrential streams and in reforesting about 425,000 acres of land, 58 per cent of which belonged to the government, 25 per cent to communities and 17 per cent to private individuals. France has now a far-reaching plan for bringing under control about 3,000 torrential streams in the Alps, Pyrenees, Ardenees, Cevenees and the central plateaus, at a cost of $40,000,000. Of this 35 per cent, or $14,000,000, is for reforestation alone.

In Austria, attention was attracted to reforestation of watersheds as a means of regulating stream flow by the great floods in the Tyrol and Kärnton. Austrian foresters enumerate over 500 torrents in the Tyrol, whose basins need reforesting, and on 100 streams the work has already begun. Similar work is being extensively carried on elsewhere among the Austrian Mountains.

In Italy the pressing need of reforesting land in the Apenines and the southern slopes of the Alps has long been urged upon the government by the people on account of the immense destruction wrought annually by the Po, which is now three times as destructive to land as it was in the past century. As a result of numerous petitions, a bill was passed in 1882, whereby waste land amounting to nearly a million acres was to be gradually reforested, involving an initial cost of $8.40 per acre beside current expenses.

The great efforts of nearly all the states of Europe to counteract the effects of indiscriminate forest clearing, efforts which involve an outlay of scores of millions of dollars, show how impor-

tant the mountain forests are. They should be regarded as a sort of capital, whose function in the national economy is far higher than the income which the timber may yield.

Forests at high altitudes, at the sources of navigable streams, on shifting sands, on banks of large rivers, and on steep exposed slopes are recognized in most of the European countries as "protective forests," and are managed with the prime object of preventing washing and erosion of soil. Thus at high altitudes on steep, exposed slopes and near the timber line, clear cutting as a rule is forbidden and timber must always be cut either in narrow strips or by gradual thinning. Severe governmental regulations controlling the management of protective forests on private lands are common in Europe. There can be little doubt that similar action will be forced upon us in the United States by the results of destroying our mountain forests.